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Indian Standard

LIQUID FLOW MEASUREMENT IN OPEN CHANNELS — VELOCITY-AREA METHOD USING A RESTRICTED NUMBER OF VERTICALS

ICS 01.040.17; 17.120.20

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BUREAU OF INDIAN STANDARDS
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NEW DELHI 110002

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Hydrometry Sectional Committee, WRD 01

FOREWORD

This Indian Standard was adopted by the Bureau of Indian Standards, after the draft finalized by the Hydrometry Sectional Committee had been approved by the Water Resources Division Council.

The measurement of discharge using the velocity-area method is a laborious and costly procedure. There is often a great temptation to use fewer verticals for the measurement than is recommended in IS 1192:1981 'Velocity area methods for measurement of flow of water in open channels' but such a short-cut can lead to considerable loss in the accuracy of the discharge determination. This standard illustrates how the accuracy of such a short-cut discharge measurement can be improved considerably by optimization of the interpolation method.

In the formulation of this standard considerable assistance has been derived form ISO/TR 9823:1990 'Liquid flow measurement in open channels — Velocity-area method using a restricted number of verticals'.

The composition of the Committee responsible for the formulation of this standard is given in Annex C.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 1960 'Rules for rounding off numerical values (*revised*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

Indian Standard

LIQUID FLOW MEASUREMENT IN OPEN CHANNELS — VELOCITY-AREA METHOD USING A RESTRICTED NUMBER OF VERTICALS

1 SCOPE

1.1 This standard describes a velocity-area method which can be carried out using three verticals only, without significant loss of accuracy, and gives advice on when such a 'short-cut' method should be used.

1.2 The method specified in this standard is not an alternative to the velocity-area method specified in IS 1192, which gives accurate results and should be used under normal conditions. This short-cut method has a limited field of application and is intended for use only in special circumstances as indicated in 7.

2 REFERENCES

The following standards contain provisions, which through reference in this text, constitute provisions of this standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below:

IS No.	*Title*
1191 : 2003	Hydrometric determinations — Vocabulary and symbols
1192 : 1981	Velocity-area methods for measurement of flow in open channels
15119	Measurement of liquid flow measurement in open channels:
(Part 1) : 2002	Establishment and operation of a gauging station
(Part 2) : 2002	Determination of the stage-discharge relation
15122 : 2002	Measurement of liquid flow in open channels under tidal condition

3 DEFINITIONS

For the purpose of this standard the definitions given in IS 1191 shall apply.

4 SYMBOLS

The symbols used in this standard are listed in Table 1. The convention has been adopted that upper case letters refer to values based on the total discharge measurement, whilst lower case letters refer to values relating to some portion less than the total.

5 THEORY

The discharge per unit width q may be expressed as:

$$q = cd^{3/2}$$

therefore

$$c = q / d^{3/2} = d\bar{v} / \mathrm{d}^{3/2} = \bar{v} / \sqrt{d}$$

and

$$C = Q\,(\bar{D}^{3/2} B)$$

With reference to Fig. 1. $\bar{v}_1$, $\bar{v}_2$ and $\bar{v}_3$ are the measured mean velocities, and d_1, d_2 and d_3 are the measured depths, at the verticals 1, 2 and 3 respectively. The mean velocity $\bar{v}_x$ at the vertical x is calculated from the equation:

$$\bar{v}_x / \sqrt{\mathrm{d}_x} = \bar{v}_1 / \sqrt{d_1} = c_1$$

and the mean velocity $\bar{v}_y$ at the vertical y is calculated from;

$$\bar{v}_y / \sqrt{\mathrm{d}_y} = \bar{v}_2 / \sqrt{d_2} = c_2$$

or

$$\bar{v}_y / \sqrt{\mathrm{d}_y} = \bar{v}_3 / \sqrt{d_3} = c_3$$

Similarly

$$\bar{v}_k / \sqrt{d_k} = \bar{v}_3 / \sqrt{d_3} = c_3$$

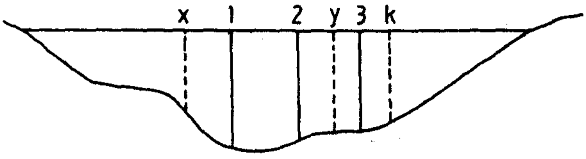

FIG. 1 CROSS-SECTION OF RIVER

6 METHODOLOGY

6.1 The method proposed has been derived from work carried out by Dutch water engineers in the Netherlands. From studies carried out on the River Rhine and on tidal rivers, they have established the following:

$$C = Q / (\bar{D}^{3/2} B)$$

$$c = \bar{v} / \sqrt{d}$$

Relationships (*see also* Table 1):

Table 1 Symbols

(*Clauses* 4 *and* 6.1)

Sl No. (1)	Symbol (2)	Quantity (3)	Dimensions (4)	Unit (5)
i)	A	Area of cross-section	L^2	m^2
ii)	B	Width of channel at water surface	L	m
iii)	C	Value derived from $C = Q/(\bar{D}^{3/2} B)$	–	–
iv)	c	Value derived at measured vertical from $c = \bar{v} / \sqrt{d}$	–	–
v)	c	Arithmetic mean of c values for a discharge measurement	–	–
vi)	$\bar{D}$	Mean depth, derived from $\bar{D} = A / B$	L	m
vii)	d	Measured depth at vertical	L	m
viii)	H	Stage, as read at gauge	L	m
ix)	Q	Total discharge	$L^3 T^{-1}$	m^3/s
x)	q	Unit width discharge	$L^2 T^{-1}$	m^3/s
xi)	$\bar{v}$	Mean velocity at the vertical	LT^{-1}	m/s

Their work has been extended to other rivers in other parts of the world, to develop these relationships to determine the optimum number of verticals and their locations.

6.2 It has been established that three verticals, located in terms of width alone, should be used. For rivers where discharge has not been measured previously, the best results appear to be given when the verticals are located at one-quarter, one-half and three-quarters of the width.

6.3 From the normal surveys carried out after the selection of the measurement section [*see* IS 15119 (Part 1)] it is necessary to derive relationships between stage and other dimensions such that a reading of stage defines the other values. Thus by reading the stage, the related width and cross-sectional area, the mean depth may be obtained.

7 APPLICATIONS

The method is applicable whenever there is an exceptional need for speed in the completion of a discharge measurement. Examples of such applications are as follows.

a) One example is that of a new measurement section on a river where measurements have not been carried out before, and where there is a need to derive a stage-discharge relationship [*see* IS 15119(Part 2)] quickly, so that studies on the potential yield of the river for some development project can commence.

b) Another example is when high stage does not permit the normal amount of time for measurement, or during flash floods when the rapid variation in the stage may limit the amount of time available.

c) A special case may be that of a gauging station which is in constant use, where expenditure constraints may dictate economies. In such a case, special calibration techniques can be used (*see* **8.2** and Annex B), which should enhance the accuracy of the results.

d) A further example is the measurement of the discharge of tidal rivers (*see* IS 15122).

8 PROCEDURE

8.1 Rivers on which no Previous Measurements have been Carried Out

8.1.1 Select the measuring section in accordance with the recommendations given in IS 15119 (Part 1).

8.1.2 Carry out a topographic and hydrographic survey of the section and install a gauge in accordance with the recommendations given in IS 15119 (Part 1).

8.1.3 From the survey data the relationships between stage and width, stage and cross-sections, stage and mean depth can be established and illustrated either through a table or a graph.

8.1.4 On arrival at the site to perform the measurements, read the stage. From the table or graph prepared in **8.1.3**, determine the corresponding values of the width, cross-sectional area and mean depth.

8.1.5 Locate the first vertical at one-quarter of the width (as determined in **8.1.4**) from the water's edge. Sound for depth and measure the velocity using a current-meter to determine the mean velocity at the vertical. Repeat these operations at verticals located at one-half and three-quarters of the width.

8.1.6 Compute c for each of the three verticals from the equation:

$$c = \bar{v} / \sqrt{d}$$

8.1.7 Carry out the computations specified in either (a) or (b) below:

a) Determine the average of the three values of c.

Assume that this value of c is equal to C and compute the discharge from the equation:

$$Q = \bar{D}^{3/2} BC$$

NOTE — See Annex A for a worked example.

b) For each of the values of c, calculate the value of $\bar{v}$ using the equation:

$$\bar{v} = \sqrt{dc}$$

Compute the discharge from the equation:

$$Q = \sum_{i=1}^{n} \bar{v}_i d_i b_i$$

where

n = total number of verticals (that is, 3); and

b_i = width of the i^{th} segment.

8.2 Rivers on which Previous Measurements have been Carried Out

8.2.1 From the original or most recent survey data of the measurement section, define the relationships specified in **8.1.3**.

Prepare a table or a graph illustrating these relationships.

8.2.2 From the existing records, compute c for each vertical of each measurement, and compute C for each total measurement. Compute the value of c/C for verticals spaced across the width at intervals of 5 percent of B for the entire range of stage.

Plot these values to give isolines of c/C as a function of the river width and stage (*see*, for example, Fig. 2). Alternatively, or in addition, plot the deviation of the c/C values from 1.00 as a function of the river width and stage (*see*, for example, Fig.3).

8.2.3 Analyse the plot(s) prepared either to determine the three verticals on which the deviation of c/C from 1.00 is minimal or to determine the three verticals on which the value of c/C is the most constant throughout the range of stage.

8.2.4 On arrival at the site to perform the measurements, read the stage. From the table or graph prepared in **8.2.1**, determine the corresponding values of the width, cross-sectional area and mean depth.

8.2.5 Locate the positions of the verticals determined in **8.2.3** by measurement from the water's edge at the appropriate bank. Sound for depth at the selected verticals and determine the mean velocity at the selected verticals using a current-meter.

8.2.6 Compute c for each of the three verticals from the equation;

$$c = \bar{v} / \sqrt{d}$$

Correct the values of c/C so obtained by multiplying them by the inverse of the corresponding mean c/C value indicated on the isoline or deviation plot.

Determine the average of the three corrected values of c.

8.2.7 Assume that $\bar{c}$ equal to C and compute the discharge from the equation

$$Q = \bar{D}^{3/2} BC$$

NOTE — *See* Annex B for a worked example.

8.3 High Stage or Flash Flood

8.3.1 In the case of a site where no previous measurements have been carried out, proceed as specified in **8.1**.

8.3.2 In the case of a site having previous measurement records, proceed as specified in **8.2**.

9 UNCERTAINTY IN THE DISCHARGE DETERMINATION

The method of using restricted number of verticals given in this standard is applicable when there is a single stage-discharge curve for the river. Quite often, the stage-discharge curve for the rising flood is different from that of the falling flood. In that case, the value of c/C will be different for the rising and falling limbs of the stage-discharge curve. It would then be necessary to draw Fig. 3 deviation of c/C from 1.00 separately for the rising and falling limbs of the stage-discharge curve for use in application of this method as illustrated in Annex B.

From the relatively restricted number of measurements taken and tested to date, indications are that the results obtained by using this short-cut method fall within ± 5 percent of the values determined using the full number of verticals in accordance with IS 1192.

Results so far indicate that the accuracy of the discharge determination is likely to be greater when previous calibration data are available for use.

However, until many more tests have been conducted on many more rivers, the order of accuracy quoted above should be treated with caution.

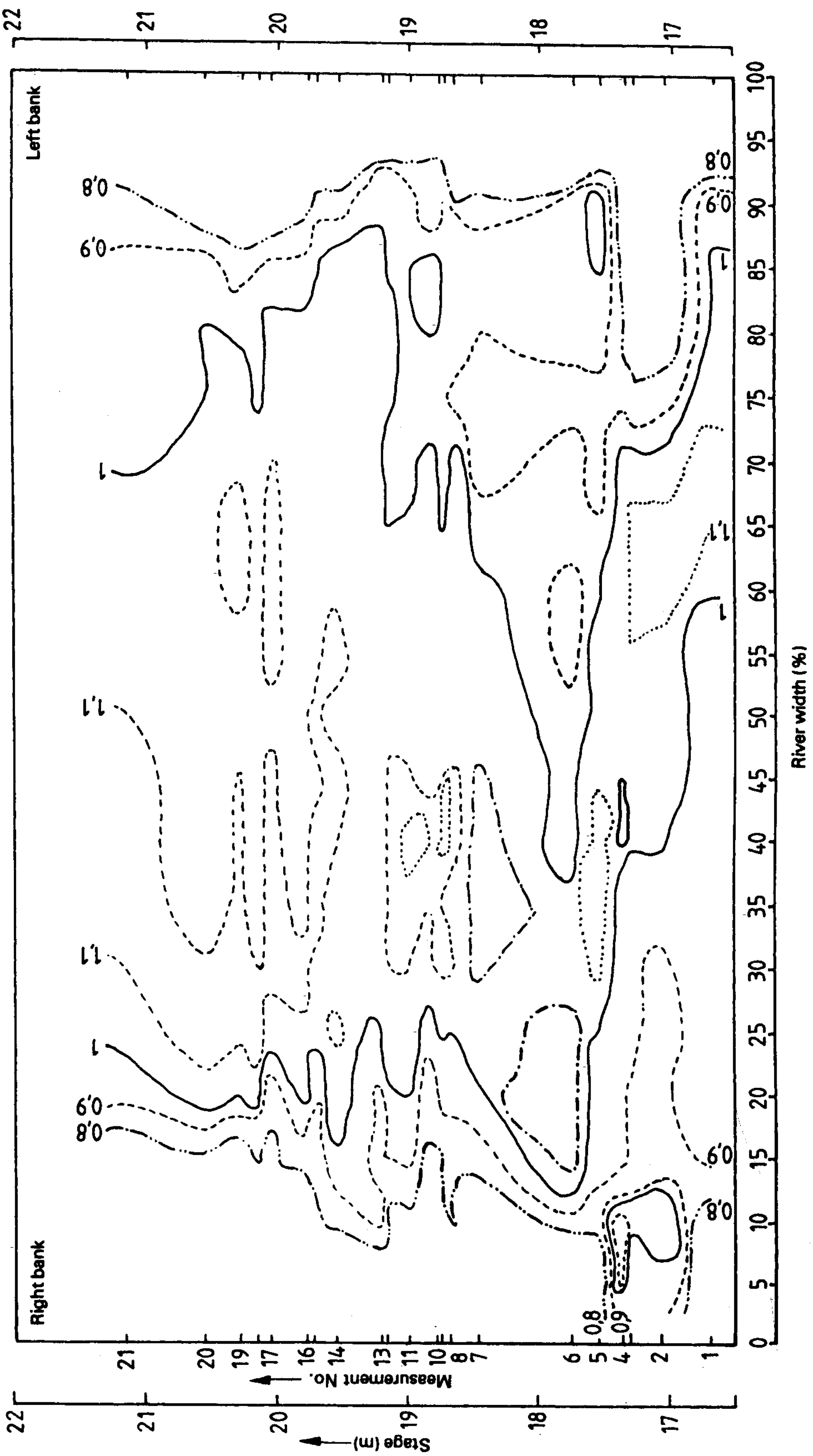

FIG. 2 ISOLINES OF *c*/*C*

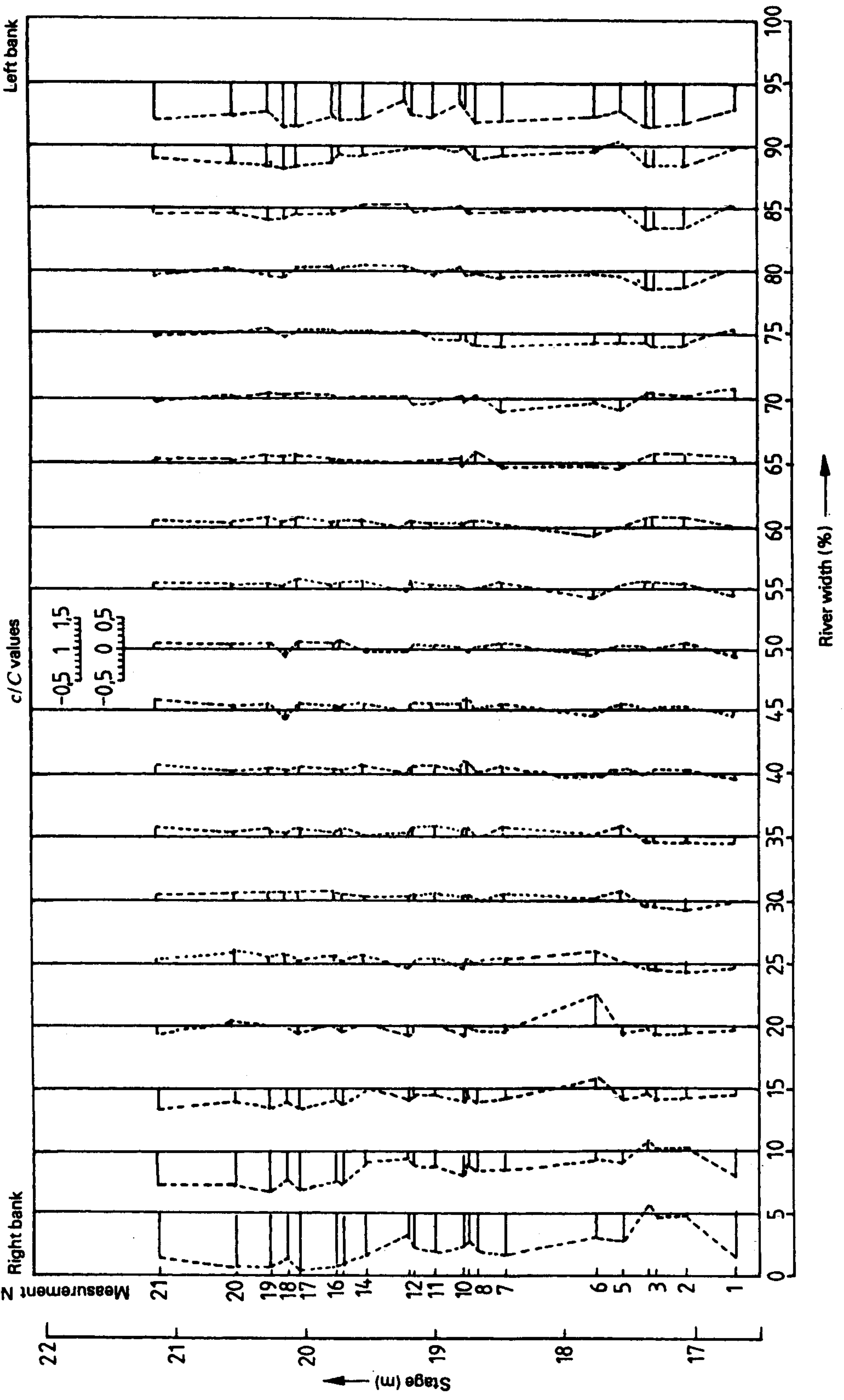

FIG. 3 DEVIATION OF *c*/*C* FROM 1.00

ANNEX A

(*Clause* 8.1.7)

WORKED EXAMPLE FOR A RIVER ON WHICH NO PREVIOUS MEASUREMENTS HAVE BEEN CARRIED OUT

A-0 This example is based on a discharge measurement, carried out using the full number of verticals, on the River Severn at Bewdley in April 1962.

A-1 Select the measuring section in accordance with the recommendations given in IS 15119 (Part 1).

A-2 Carry out a topographic and hydrographic survey and install a gauge on the river bank in accordance with the recommendations given in IS 15119 (Part 1).

A-3 From the survey data, prepare tables or graphs of stage H *versus* width B, cross-sectional area A and mean depth $\bar{D}$ for the measuring section.

A-4 On arrival on site to perform the measurements, read the stage.

From the tables or graphs (*see* **A-3**),determine the corresponding values of B, A and $\bar{D}$.

In this case, the following values were determined : stage, $H = 19.2$ m; cross-sectional area, $A = 100.67$ m^2 width , $B = 46.33$ m; mean depth, $\bar{D} = 2.173$m.

A-5 Locate the positions of the verticals at one-quarter, one-half and three-quarters of the width, that is, at 11.58 m, 23.17 m and 34.75 m from the edge of the water on either bank.

Sound the depth at each of the selected verticals.

Determine the mean velocity at each vertical using a current-meter. In this case, the following values were determined:

a) at one-quarter of the width: depth, $d = 2.347$ m; mean velocity, $\bar{v} = 0.779$ m/s;

b) at one-half of the width: depth, $d = 2.755$ m; mean velocity, $\bar{v} = 0.859$ m/s; and

c) at three-quarters of the width: depth, $d = 2.438$ m; mean velocity, $\bar{v} = 0.838$ m/s;

A-6 Compute c from $c = \bar{v} / \sqrt{d}$ for each of the three verticals:

a) at one-quarter of the width, $c = 0.508$;

b) at one-half of the width, $c = 0.517$; and

c) at three-quarters of the width, $c = 0.537$.

A-7 Follow the procedure specified in **8.1.7** (a) or (b). In this case, the procedure specified in **8.1.7** (a) is followed.

Compute the average value of c, that is, $\bar{c} = 0.521$

Assume that $\bar{c} = C$, and compute the discharge from $Q = \bar{D}^{3/2} BC$, that is, $Q = 2.173^{3/2} \times 46.33 \times 0.521 = 77.32$ m^3/s.

A-8 The discharge value obtained from the measurements using the full number of verticals was 78.35 m^3/s .The discharge value obtained using this method differs from the full value by –1.31 percent.

ANNEX B

(Clauses 8.2.7 *and* 9)

WORKED EXAMPLE FOR A RIVER ON WHICH PREVIOUS DISCHARGE MEASUREMENTS PROVIDE A GOOD RECORD

B-0 This example is based on a discharge measurement, carried out using the full number of verticals, on the River Severn at Bewdley in 13th April 1962.

B-1 The following results were obtained from this discharge measurement:

stage, H = 19.2 m;
discharge, Q = 78.36 m^3/s
width, B = 46.33 m;
mean depth, $\bar{D}$ = 2.173 m;
C = 0.528 [from Q / ($\bar{D}^{3/2}$ B)];
cross-sectional area, A = 100.67 m^2

From the survey data, define the relationships and prepare tables or graphs of stage H *versus* width B, cross-sectional area, A and mean depth, $\bar{D}$ for the measuring section.

B-2 From the existing records, compute the c/C values at all measured verticals and extrapolate these values to verticals spaced at intervals of 5 percent of the stream width for all available stages.

Plot these values in the form of isolines of c/C (*see* Fig. 2) and also as deviations from c/C = 1.00 at the 5 percent verticals (*see* Fig. 3).

B-3 Select the verticals which show the greatest consistency in the value of c/C throughout the range of stage. In this case, verticals have been selected at 35 percent, 50 percent and 60 percent of the width, from the right bank.

B-4 On arrival on site to perform the measurements, read the stage.

From the tables or graphs (*see* **B.1**), determine the corresponding values of B, A and $\bar{D}$.

In this case, the following values were determined:

stage, H = 19.2 m;
cross-sectional area, A = 100.67 m^2 ;
width, B = 46.33 m;

Confirm that the verticals located at 35 percent, 50 percent and 60 percent of the width are valid.

B-5 Locate the positions of the verticals, measuring from the water's edge on the right bank, that is, 35 percent of B = 16.215 m; 50 percent of B = 23.165m; 60 percent of B = 27.798 m.h.

Sound the depth at each of the selected verticals

Determine the mean velocity at each vertical using a current-meter. In this case, the following values were determined:

a) at 35 % of B: depth, d = 2.452 m; mean velocity, $\bar{v}$ = 0.872 *m/s;*

b) at 50 % of B: depth, d = 2.755 m; mean velocity, $\bar{v}$ = 0.859 *m/s*; and

c) at 60 % *of* B: depth, d = 2.782 m; mean velocity, $\bar{v}$ = 0.882 *m/s.*

B-6 Compute from $c = \bar{v}\ \sqrt{d}$ for each of the three verticals:

a) at 35 percent of B. c = 0.557:

b) at 50 percent of B. c = 0.518; and

c) at 60 percent of B. c = 0.529.

Correct the values of c by multiplying them by the inverse of the corresponding mean c/C value:

a) at 35 percent of B, c/C = 1.055; correction factor, $1/(c/C)$ = 0.948; corrected, c = 0.528;

b) at 50 percent of B, c/C = 0.981; correction factor, $1/(c/C)$ = 1.019; corrected, c = 0.528:

c) at 60 percent of B, c/C = 1.002; correction factor, $1/(c/C)$ = 0.998; corrected, c = 0.528.

Compute the average value of the corrected values of c, that is, $\bar{c}$ = 0.528.

B-7 Assume that $\bar{c}$ = C and compute the discharge from $Q = \bar{D}^{3/2}$ BC, that is, Q = 2 173$^{3/2}$ × 46.33 × 0.528 = 78.36 m^3/s.

B-8 The discharge value obtained from the measurements using the full number of verticals was 78.35 m^3/s. The discharge value obtained using this method differs from the full value by only +0.01 percent.

ANNEX C

(*Foreword*)

COMMITTEE COMPOSITION

Hydrometry Sectional Committee, WRD 01

Organization	*Representative(s)*
Central Water Commission, New Delhi	Shri M. K. Sharma (***Chairman***)
AIMIL Private Ltd, New Delhi	Shri S. C. Jain Shri K. S. Subramaniam (*Alternate*)
Bhakra Beas Management Board, Punjab	Director (WR) Senior Design Engineer (WR) (*Alternate*)
Central Water & Power Research Station, Pune	Shri A. R. Chavan Shri B. S. Kulkarni (*Alternate*)
Central Water Commission, New Delhi	Shri S. K. Sengupta Director (RD) (*Alternate*)
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In personal capacity (*425/14 T.V. Nagar, Pune* 411 037, *Maharashtra*)	Dr S. V. Chitale
BIS Directorate General	Director and Head (WRD) [Representing Director General (*Ex-officio*)]

Member Secretary
Shri S. S. Sethi
Scientist 'F' and Head (WRD), BIS

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